

You may have heard of Zero Energy Homes—energy self-sufficient, solar-powered homes; homes without utility bills, or nearly so. But you look at the utility bills for your own home and the cost of solar energy systems, and you wonder just how this can work. There are four essential ingredients to making a Zero Energy Home work:

- The Zero Energy Home is primarily powered by **photovoltaic and solar hot water systems**, both likely mounted on the roof.
- The Zero Energy Home is so efficient—as much as **90% more efficient than the average home**—that demand for power can be met, or nearly met, with readily available and reasonably sized solar power systems.
- The Zero Energy Home always needs a back-up—some energy from the grid in the case of the Cottage—to deal with times when the weather and the big energy demands (space heating or cooling, water heating, and refrigeration) combine and conspire.
- The fourth ingredient is **you**. To tread this lightly on the land requires that you are a part of the system, tuning your energy use to complement rather than stress the Zero Energy Home. This does not mean thermal privation or hand-cranking your radio—it means learning a lot about how your home works, occasionally outwitting the big energy demands, and maybe expanding your comfort zone just a bit.

So, the trick is to stock your roof with panels; your home with the most efficient and integrated exterior envelope, HVAC system, water heater, appliances, and lighting available; and your family with zero energy savvy. You will have to do **all three**. Here is what it takes to do each.

**The Ultra-Efficient Home Performance** Although most people associate the term zero energy with solar panels, the starting point must always be the efficiency of the structure and its heating/ventilation/air conditioning (HVAC) system. The way to really fine-tune the energy performance of a home is to treat the structure and the HVAC system as integrated systems, matching their features and individual contributions to the whole.

1. The exterior walls, floors, roof, and windows – These are all of the components of the exterior envelope. How much they resist heat conduction (their R-value), how airtight they are, and how they are oriented with respect to the sun and prevailing winds (particularly windows) all are major determinants of energy performance. The home design, the materials selected, and the quality of installation must work together to achieve maximum efficiency. A key component of the Captain Planet Cottage is the **Structural Insulated Panels**—or SIPs—used for the roof, floor, and walls. SIPs are typically made using expanded polystyrene (EPS), or polyisocyanurate rigid foam insulation sandwiched between two structural skins of oriented strand board (OSB). The result is a building system that is very strong, predictable, energy-efficient and cost-effective. Their superior R-value and air tightness are essential to the high performance of the Cottage.

The Captain Planet Cottage is designed for **passive solar heating and cooling**. Key elements include:

- home layout and orientation;

U.S. Department of Energy



Program Partner

# Captain Planet Zero Energy SIPS Cottage

Atlanta, Georgia

Builder: Certified Living, Inc.

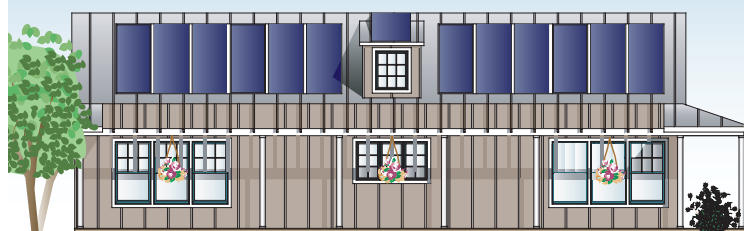
Sponsor: Captain Planet Foundation

1,700 sq. ft. home with 2 bedrooms, 2 bath and a loft

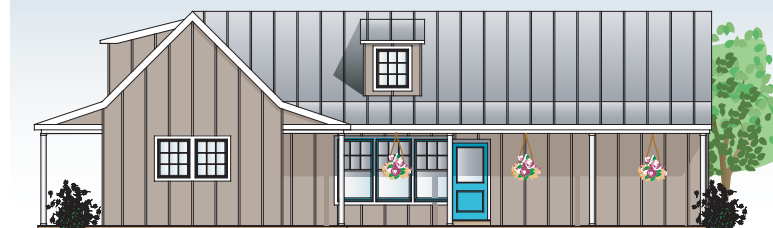
## Key Features

- Photovoltaic system
- Solar hot water heating
- Passive solar design
- Ducts in conditioned space
- Controlled ventilation
- High performance envelope, windows and an integrated HVAC system
- Advanced framing with structural insulated panels (SIPs)

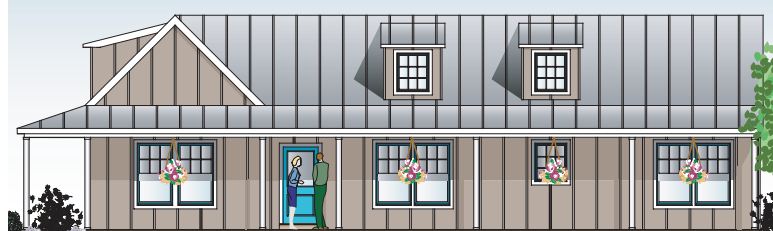
South Elevation



North Elevation



East Elevation



West Elevation



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- location, placement, number, and operability of windows;
- strategic employment of retractable porch awnings and thermal window shades;
- high ceilings and deep wrap-around porches
- highly reflective white standing seam metal roof cladding.

These all work to capture the most sun in the winter, and provide the most shading and natural ventilation in the summer.

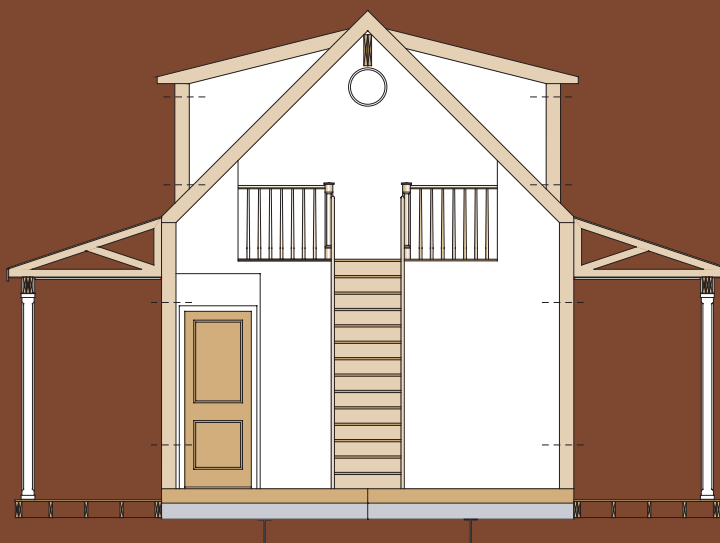
2. The HVAC system – Building a high-performance structure allows you to really fine tune or “right-size” your space heating and cooling unit, your fresh-air ventilation, and the ducts that deliver all three. Essential elements to the Cottage include a variable-speed ECM air handler, a two-stage 12 – 13 SEER AC unit, and a scheduled intermittent **fresh air ventilation system** that also provides mixing of all interior air. Mechanical ventilation, you say? You can’t build a home this tight and not purposefully introduce the fresh air you and your family need. And for the Cottage, occasional space heating needs that cannot be met by passive solar gain are supplied by the high-efficiency, direct-vent gas fireplace and distributed throughout the cottage by the mechanical ventilation system.
3. Water heating – After your HVAC system, water heating makes up the largest single energy demand in the home. Solar water heating (described below) is an **essential part of any zero energy strategy**, but you always need a back-up. While there are several options to consider—combo systems (combining water and space heating), heat pump water heaters, instantaneous systems—the Captain Planet Cottage simply has the top-of-the-line electric tank water heater. It does the best job of storing thermal capacity from the panels while relying primarily on the substantial PV capacity of the Cottage.
4. Lighting and appliances – Once the energy performance of the structure, the HVAC, and water heating have been optimized, “**plug loads**” become the next target for significant energy improvements. It begins with the big boys—the refrigerator and lighting—and reaches down to the dishwasher, dryer, and household items such as the television and microwave. The higher performance of many of these items also reduces air conditioning needs in climates with any cooling period.

**The Photovoltaic System** To turn sunlight into household electricity requires:

- panels - to collect the solar energy and convert it into direct current (DC) electricity.
- an inverter - to convert the DC into alternating current (AC), matching your home’s conventional electrical system.
- a controller – to manage where the solar and grid-supplied power go, to or from your house and the grid.

Over the past few years, each of these components has been rapidly evolving and improving so that today they are compatible, code-compliant, and cost-effective. Lots of work has been done to bring the efficiency of the panels up and their cost down, and to link the panels into system packages so that you don’t have to build the system. And in many states (and maybe the whole country with residential energy efficiency legislation pending in Congress), rebates and tax incentives exist to subsidize solar equipment investment.

Section through  
East-West Elevation



## Captain Planet Zero Energy SIPS Cottage

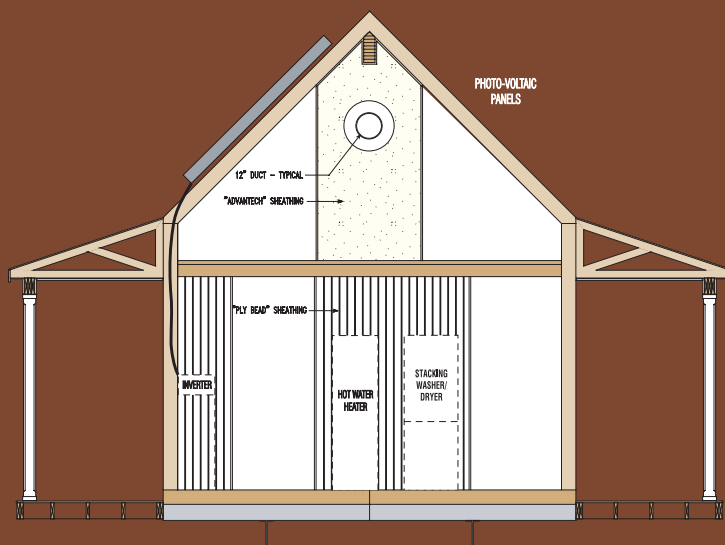
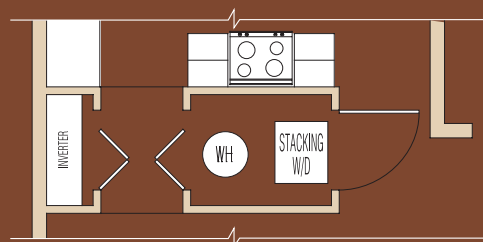
Zero Energy Homes Powered by Solar & Efficiency

SIP homes use ZERO energy when combined with solar

Lower heating bills translates to lower energy (fossil fuel) consumption and greenhouse gas emissions

ORNL study shows air leakage for SIPs is almost 15 times less than for typical wood frame construction

[www.captainplanetfdn.org](http://www.captainplanetfdn.org)



Section through  
Kitchen at Mechanical Closet

For the Captain Planet demonstration cottage of 1,700 square feet with a family of four, a 4-kilowatt system with eight 7-foot by 6-foot panels will supply nearly all of the home's electrical needs. Like most PV systems, the Captain Planet PV system costs about \$6 per watt. But the system will continue generating power with little to no replacement for many years.

**The Solar Hot Water System** To turn sunlight into hot water requires:

1. roof panel(s) – essentially box “greenhouses” containing highly absorbent piping and faced with double-glazing that lets light in yet traps significant heat energy for the piping to capture.
2. transfer piping – this carries the liquid heated in the panels (either pure water in direct systems or a coolant/water mix in indirect systems) down to either a storage tank or the water heater tank (direct system) or to a heat exchanger (indirect system).
3. tank – since the sun does not always shine, solar heated water must be stored and the volume and insulation of this tank must be matched to the capacity of the roof panel(s).

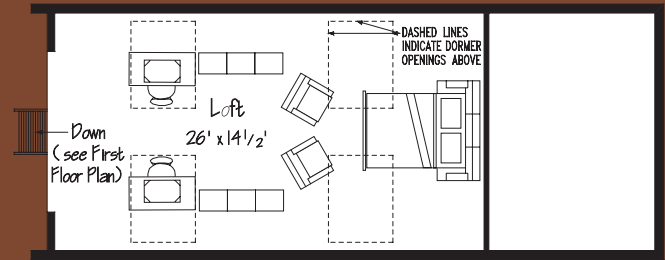
In the Captain Planet Cottage, one 4' x 8' collector at peak efficiency (when the sun is in a cloudless sky is shining directly over the panels) supplies most of the hot water for a family of four's daily needs (bathing, clothes and dish washing).

### The Zero Energy Home Owner

You can't fine-tune the energy performance of a home like this without being a smart home operator and maintainer. **You** will determine whether the term “grid back-up” is spelled with a lower or upper case “g.” **You** will determine how often your meter runs forward (you pay them) or backward (they pay you) as part of **net metering**. Here are some of the “little” things that will help determine just how close to Zero Energy your home can be:

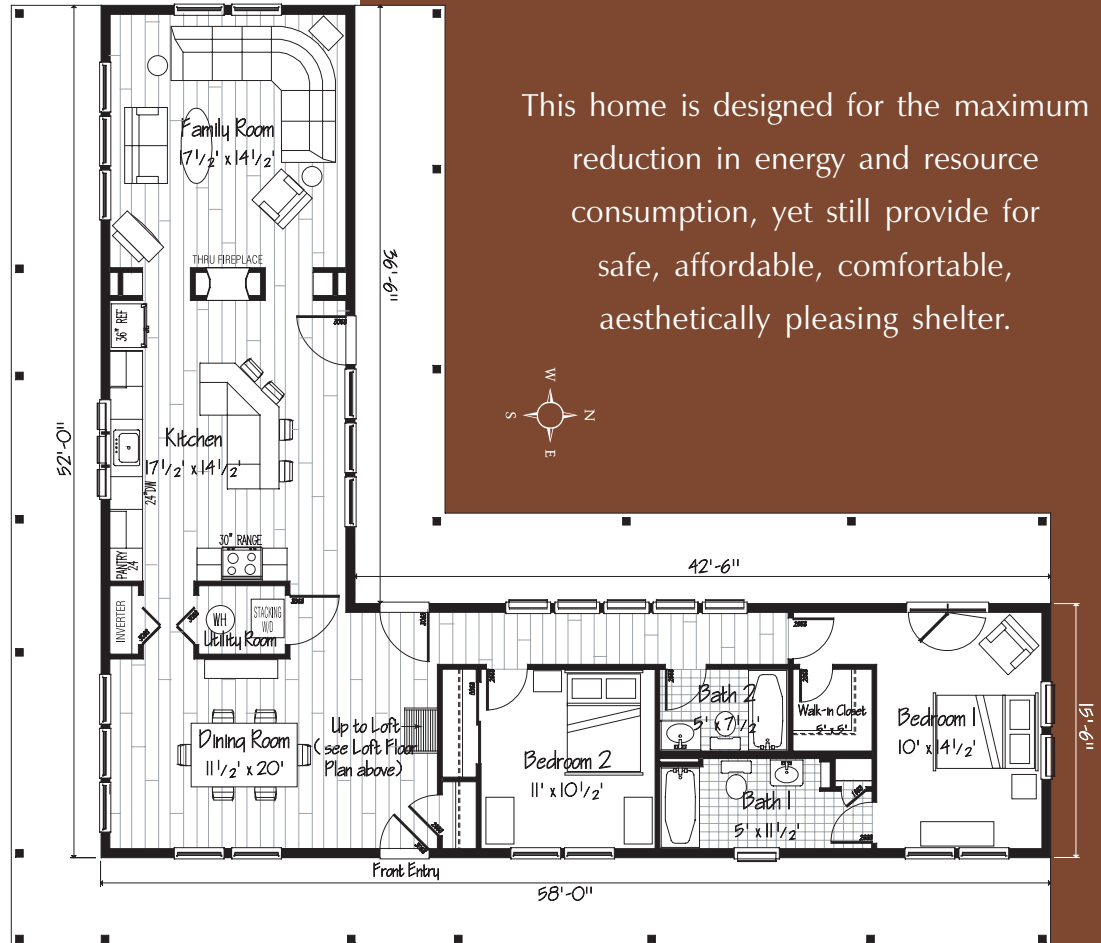
- Use your windows, insulated window shades, and retractable porch awnings for best cooling and heating effect.
- Manage your hot water needs—showering, clothes and dishwashing—to coincide with peak solar performance.
- Treat all electrical use—ceiling fans, lighting, TV, computers—as task-oriented: on when used, off when not.
- Manage daily household activities for maximum heating and cooling benefit during extreme outdoor conditions—microwave use instead of stovetop cooking and baking in the summer, or exercise routines in the winter.

**Follow home component maintenance schedules religiously.**



Zero Energy Cottage  
Loft Floor Plan

This home is designed for the maximum reduction in energy and resource consumption, yet still provide for safe, affordable, comfortable, aesthetically pleasing shelter.



Zero Energy Cottage  
First Floor Plan

### A Word on Durability

We have a nickname for the Captain Planet Zero Energy Cottage—the “double-naught” Cottage. The second zero stands for its tiny footprint in terms of materials use. This home is engineered for optimal use of materials and durability. From the wrap-around porches to the standing-seam aluminum roof, this Cottage has been designed and commissioned with components and systems for outstanding service life. The motto for the “double-naught” Cottage is “zero is more, long is less.”



# Captain Planet Zero Energy SIPS Cottage (ZE)

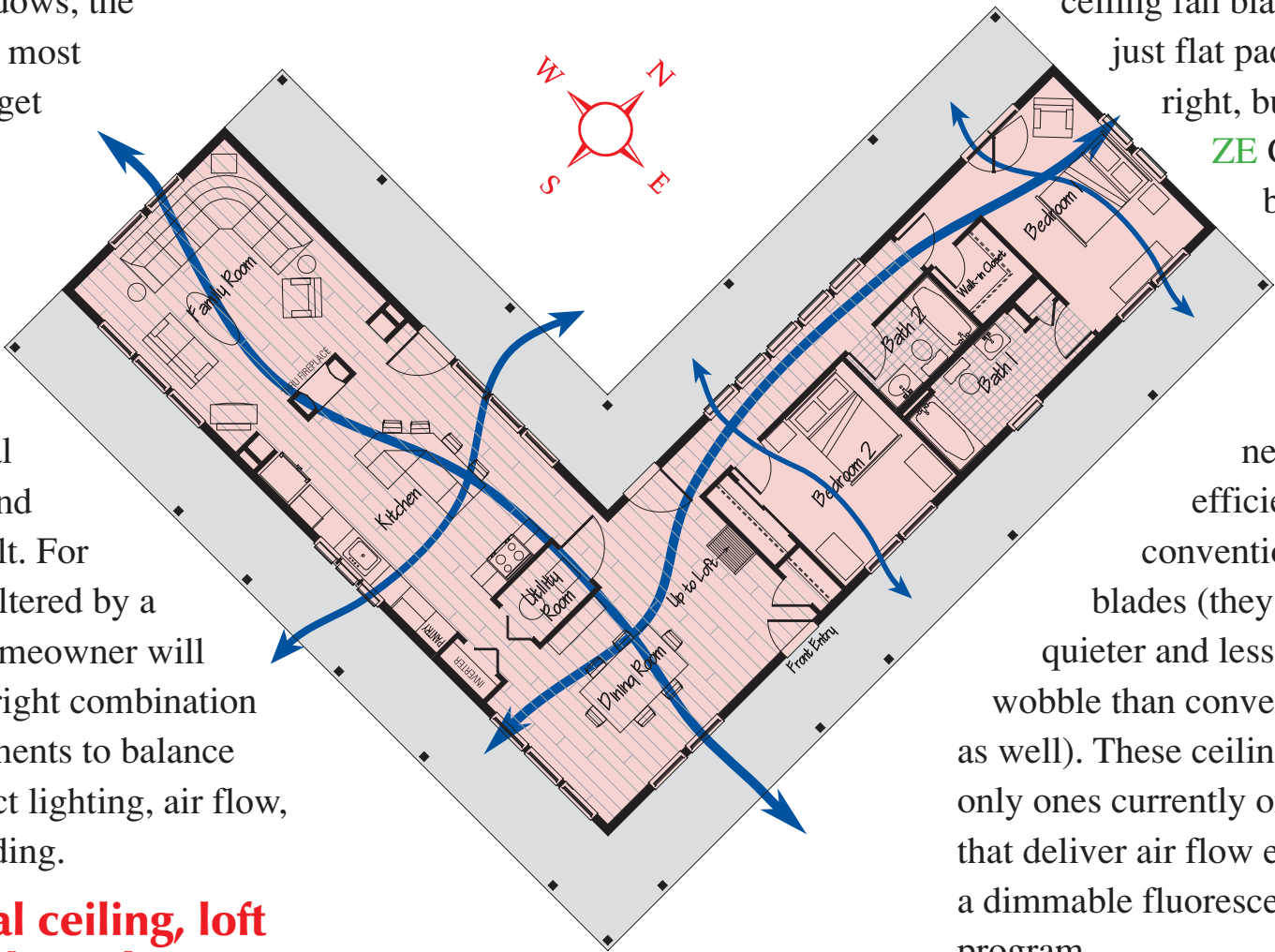
## Home Owner: Mastering Light and Air

Most people find the open and airy design of the ZE Cottage really appealing. Well, the Cottage is actually more than just a “pretty face”—it’s design is a perfect example of form meets function. Here’s how:

- **The “L” design** With the right mix of windows, the “L” design is the most effective way to get daylight in and natural ventilation through every room in the home. The ZE Cottage will be a real miser on lights and cooling as a result. For windows not sheltered by a porch, the ZE homeowner will have to find the right combination of window treatments to balance direct and indirect lighting, air flow, and summer shading.

- **The cathedral ceiling, loft dormers, and porches** Everyone knows that hot air rises (hot air is less dense than cooler air). The ZE Cottage’s high ceilings take advantage of this “stack effect,” and the loft window dormers act as “chimneys” for exhausting

the hot air. The result is cooler air being pulled in off the large sheltered porches. How do we know that all these features will work together like this? The answer comes from homes built 100 years ago, before artificial lighting and mechanical heating and cooling.



- **The mechanical ventilation system** Our fresh air needs don’t go away during the height of summer and winter, when our homes are closed up. Many homes today count on random air infiltration through a leaky building envelope under summer and winter conditions—a big mistake. This accidental air could hardly be called fresh; it can be laden with humidity, dust, building material fibers, etc. The ZE Cottage pulls in just the right amount of outdoor air through a dedicated duct from a consciously located external port. This fresh air is then filtered and mixed with circulating indoor air, tempering it’s temperature difference so that the

ZE home owner only notices... comfort.

- **“Form meets function” ceiling fans** If you look closely at the ceiling fans in the ZE Cottage, you will notice a graceful twist to their blades—aren’t ceiling fan blades usually just flat paddles? You’re right, but not in the ZE Cottage. The blades are bent like a propeller blade, moving air nearly 50% more efficiently than conventional flat fan blades (they are much quieter and less prone to wobble than conventional blades as well). These ceiling fans are the only ones currently on the market that deliver air flow efficiently, with a dimmable fluorescent light, with a program-

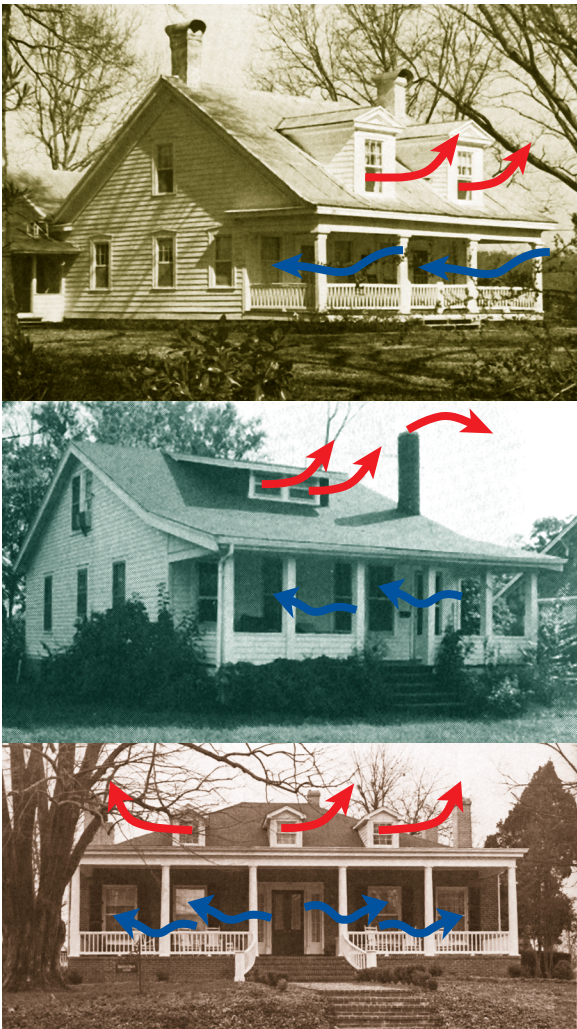
mable remote control. You can program the fan on a timer or to a temperature, so that the fan only spins for occupant comfort. Most ceiling fans run longer than necessary for occupant comfort or run when no one is in the room, when the only result is wasted energy and the ceiling fan motor heating, not cooling the air!



**Isn’t it great to have a home that works as well as it looks?**

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 U.S. DEPARTMENT OF ENERGY



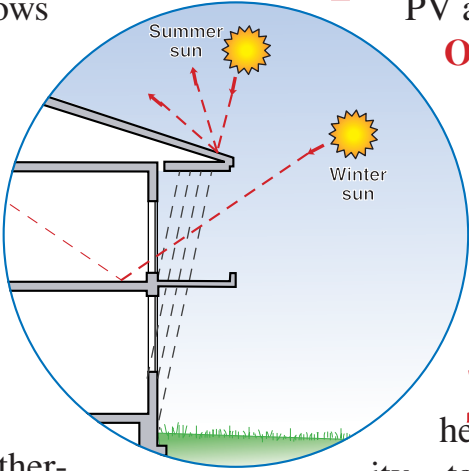
# Captain Planet Zero Energy SIPS Cottage (ZE)

## Home Owner: Mastering Power Demands

We are so accustomed to ready, virtually unlimited power that most of us don't know just how much it takes to power our homes and all their conveniences. ZE home owners must be students of the Btu<sup>1</sup> and the watt<sup>2</sup>.

**Managing the Btu** We use Btus to talk about heating (welcoming or adding Btus) and cooling (keeping or taking out Btus) the building. A ZE home owner negotiates Btus with the sun first, the gas or oil man second. During the heating season, the ZE home and owner take advantage of the way the home is designed, positioned, and operated to bring as much sun (a free source of Btus) into the building as possible:

- Overhangs and windows – both with dimensions and locations to admit low-angle winter sun.
- Awnings and thermal shades – opened or pulled up to admit low-angle winter sun during the day with thermal window shades closed to retain Btus at night.



During the cooling season, the ZE home and owner take the opposite approach, keeping out as much direct sun (btus) as possible:

- Overhangs and windows – dimensions and locations keep out high-angle direct sun.
- Awnings and solar screens – Retractable awnings fully extended to shade walls and windows; solar screens on window to shade without unduly restricting viewing.<sup>3</sup>
- Operable windows and ceiling fans – Relative humidity permitting, free or really cheap cooling can be had by moving air through the building and around occupants.

Lastly, a high-efficiency gas furnace/fireplace provides Btus or supplemental heating during the heating season, with the **mechanical ventilation system** distributing this heat throughout the house. The ZE home high-efficiency air conditioning system provides supplemental cooling

and dehumidification for comfort when a breeze from windows and ceiling fans just can't cut it. Both the two-stage compressor and variable-speed, electrically-commutated (ECM) air handler motor are designed for peak efficiency and maximum removal of vapor (latent load) from interior air. Both the furnace and the A/C are controlled by a smart, **programmable thermostat**, further boosting the HVAC system's efficiency.

**Managing the watt** We use the watt to talk about electrical power. Being watt-wise is how the ZE home and homeowner can really shine, or fade, primarily for two reasons:

**1** The ZE home's solar systems—the PV and solar water panels—**ONLY** negotiate with the shining sun. Without any battery storage and only limited hot water tank storage, the ZE homeowner must match timely supply with timely demand for watts.

**2** Moving Btus with watts—heating or cooling with electricity—takes a LOT of power. Any electrical appliance or home convenience that heats—a toaster, a hair dryer—or cools—primarily the refrigerator—will require the most “watt” diligence.

So, the ZE home owner needs to use the following information about types and sources of demand for watts to maximize business with the ZE home's solar systems and minimize (at least incoming) business with the utility. Remember that there are three aspects of any electrical fixture that are important in managing watts—how much power it draws, how long it operates each day, and when it operates each day.

**Use these guidelines** with the table to the right to manage household energy use:

- Make hay—or coffee or clean clothes or toast—while the sun shines. As much as possible, pace use

of significant watt gobblers with your PV system's production.

- Capitalize on your **investment** in your ZE home with high-efficiency appliances. Use the table below to decide on which items you will get the best return. Use the EPA Energy Star label as a guide.



- Consider every electrical use as a task—on when in use, off when not. This goes for just about everything—lighting, fans, entertainment equipment. As the table shows, they all can draw lots of watts.
- Use fluorescent fixtures and bulbs—the quality and availability has and continues to improve—use the EPA Energy Star label as a guide.
- Watch your “**vampire**” loads—devices that use energy while plugged in but not functioning. These loads can really add up, particularly for those devices with step-down transformers (adapters) and devices with built-in clocks.
- During the cooling season, manage watts for Btu production, those appliances or fixtures that create heat.

watts used	
coffee maker .....	900—1,200
clothes washer .....	350—500
clothes dryer .....	1,800—5,000
dishwasher .....	1,200—2,400
(using the drying feature greatly increases energy consumption)	
ceiling fan .....	65-175
hair dryer .....	1,200—1,875
clothes iron .....	1,000—1,800
microwave oven .....	750—1,100
Personal computer:	
CPU (awake) .....	120
monitor (awake) .....	150
radio (stereo) .....	400
refrigerator (16 ft <sup>3</sup> frostfree) .....	725
27" television .....	113
toaster .....	800—1,400
vacuum cleaner .....	1,000—1,400
water pump (deep well) .....	250—1,100

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**1** A British thermal unit (Btu) is the amount of heat energy it takes to raise the temperature of one pound of water by one degree Fahrenheit (at sea level). As an example, it takes about 2,000 Btus to make a pot of coffee.

**2** A watt is the basic unit of electrical power. As an example, if you took two 2-liter plastic bottle of soda, one in each arm, and lifted it up three feet in one second over and over again, you would spending the same amount of power as a 40-watt light bulb—tough way to read a book, huh?

**3** A note of caution: thermal window curtains can NOT be used to keep summer sun out during the day because very warm even hot air is trapped between the shade and glazing, possibly creating temperatures high enough to damage the sealed multi-paned glazing units.



# Captain Planet Zero Energy (ZE) Home Owner: Mastering Solar Energy Systems

Just about the entire roof area on the south side of the ZE Cottage is stocked with solar panels, 40 photo-voltaic and one solar water to be exact. The renewable energy system installed by Big Frog Mountain Corporation consists of photo-voltaic panels from Evergreen Solar. The panels are mounted using Unirac’s mounting system and metal roof clamps by S-5!. The DC current generated by the panels is converted to utility-grade 120 volts (household current by the multimode inverter built by Advanced Energy Inc.). The system is designed to turn the utility meter backwards during the day. The system is on the south side because this gets the most direct solar exposure year round. Here is how it works:

## Photo-voltaic (PV) panels

PV panels turn a portion of the sunlight (photo) they receive into electricity (voltaic). PV or solar cells are made up of silicon wafers, one layer “doped” with a substance that tends to give up electrons when excited by incoming photons (solar energy units) and another layer doped with a substance that tends to take on excited electrons (the silicon crystal base is a great background for this exchange of electrons because silicon atoms tend to loosely share lots of electrons in this crystal structure). And whenever you create a flow of electrons, you get electricity.

The tricks to making solar cells for everyday use have been developing the technology to mass produce cells (even before “mass” demand exists), developing the technology to boost how much sunlight they can convert into electrical current, and developing the technology to support safe and efficient integration into existing electrical systems.

The ZE PV system has two other important major components besides the array of forty panels—an inverter and a controller. A long time ago, for a variety of reasons related to materials, safety, and transmission issues, we decided to run buildings, including homes, on alternating current (AC). But the PV panels produce direct current (DC). The inverter changes the DC into AC current compatible with household electrical systems. The last component, the controller, controls the flow of energy from the panels, to the house, and to and from the utility power lines. An important part of the controller’s job is to prevent current from entering the line when utility lineman have interrupted the utility supply for line maintenance or repair.

The size or capacity of PV systems is generally expressed in terms of **watts** or **kilowatts** generated under peak or ideal conditions. The ZE PV system is capable of generating about 10 watts per square foot of panel, for a total of 4,000 watts or 4 kilowatts. Given the efficiency of the Cottage’s building envelope, its HVAC system, and appliances, 4kW will more than meet the total annual demand over the course of an

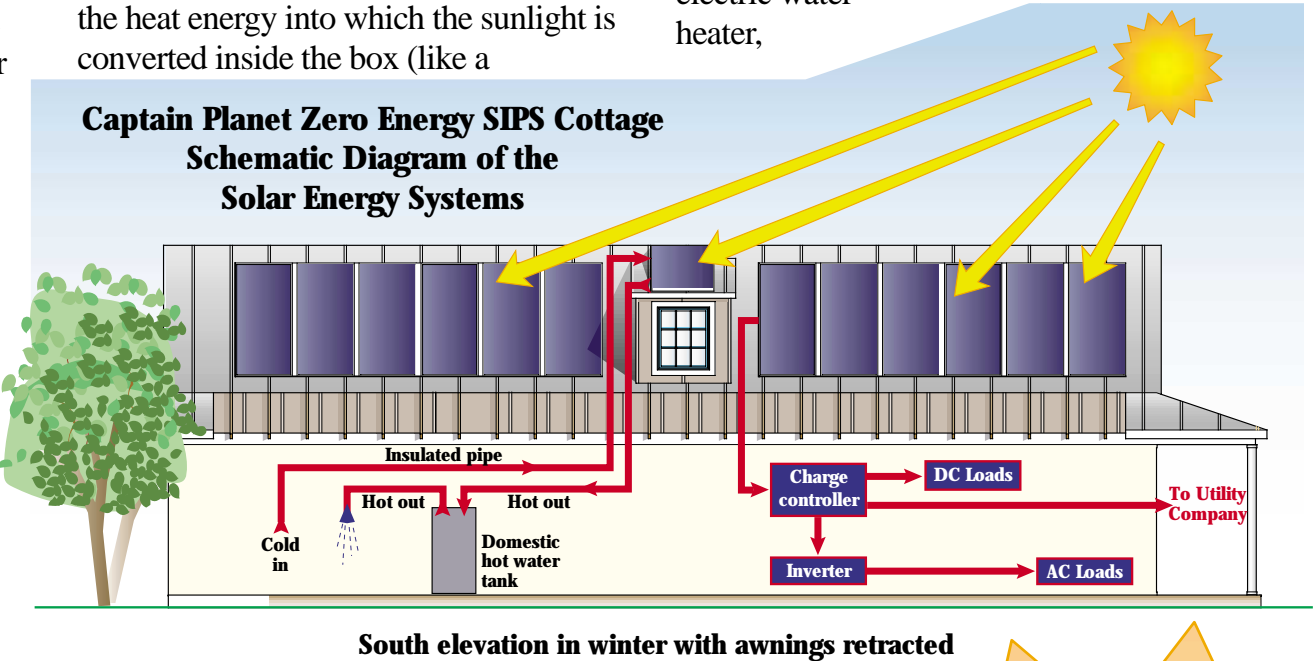
entire year, **depending** on the patterns and nature of energy use by its occupants. And here is the really neat part—managing their energy uses is pretty much all that ZE owners need to do—the PV system is virtually maintenance-free during its 20+ years of expected operation.

**Solar water panel** All solar water heaters have the following components:

- an open-faced roof-mounted box with a dark, highly absorptive inside surface;
- a glass top face that permits sunlight to pass into the box but is relatively reflective to the heat energy into which the sunlight is converted inside the box (like a

specific installation and length of exposed transfer piping.

The ZE Cottage CopperSun system is a passive open-loop system—no pumps, no moving parts, no valves, no controller. This is a very simple yet sophisticated solar water system with a good track record in the field. This 4 by 8 panel has been custom-made to be oriented up and down the shed roof of the dormer window on the south elevation of the ZE roof. The hot water from the roof panel circulates to the standard 50-gallon storage tank of the electric water heater,



- greenhouse);
- highly conductive piping inside the box, filled with a fluid that can pick up a significant portion of the heat energy trapped in the box;
- insulated piping that carries the heated fluid down into the building, for hot water use or heat exchange to water for use.

There are two ways of classifying the major differences among solar water systems—active versus passive and closed-loop versus open-loop. Active systems all have pumps controlled by a thermostat that move fluid through the system. Passive systems have **no pumps**; they rely upon either thermo-siphoning or density differences brought on by temperature to move fluid through the system. Closed-loop systems have two loops—one loop goes to the solar collector and contains a fluid (generally a water-antifreeze mix) that transfers heat well but has a very low freezing point. This fluid exchanges its heat content with potable water in a separate loop. Open-loop systems have only one loop of potable water.

Generally, active and closed-loop systems have **significantly higher efficiencies** and can be used in climates with freezing conditions. Many passive and/or open-loop systems are only appropriate for areas with no or only occasional mild freeze conditions. Passive and open-loop systems are less complicated and hence less expensive. But open-loop systems are very dependent on high-quality water for efficient operation and reasonable service life. Closed-loop systems must have either a drain-back or warm water trickle feature to deal with freeze conditions, but much depends on the

basically keeping the electric elements of the water heater off or working less. The ZE homeowner will only know the panel is working by looking at the paltry electric bill.

This solar panel will supply most of the hot water needs for a family of four, **depending** on weather and the hot water use of the occupants. Anyone can save money with this unit, but the ZE home owner that times major hot water use to the late afternoon/early evening peak production period of the system will be the real winner.

The CopperSun is designed for temperate climates with limited freeze potential. It is rated for 20° F for an 18 hour period. The two freeze protection systems required by the Solar Rating Certification Corporation are the high mass 4-inch tubes and the drain down system for rare times in the Atlanta climate when conditions could exceed the rated conditions.

**Many PV systems have batteries for storing electricity when PV supply is greater than household demand. PV battery systems are currently still very expensive and not particularly long-lived. While batteries are nearly essential for off-the-grid systems, they are not a part of the ZE Cottage grid-tied system. Many off-the-grid PV systems also have a back-up generator, which runs to supply household demand for extensive periods of bad weather and/or to periodically top off the battery charge.**